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ABSTRACT

The ways in which students in grades five and six solve problems is the focus of this paper, which provides background for the staff of the Skills Essential to Learning Television Project, (a multi-level series of video and print resources for classroom use). It considers the problem-solving process categories of understanding, transformation, and composition; the kinds of situations in which students are expected to solve problems; and the kinds of problems they are expected to solve. Problem solving in mathematics, understanding in reading stories, and understanding in science are used as examples of school tasks. It is concluded that problem solving should not be considered as a single, uniform capability, and that problem solving does not occur in a vacuum. Four general aims are suggested for an instructional program focusing on problem solving: strengthening skills for conventional problems, enlarging students' knowledge base for problem solving, expanding students' problem-solving skills, and teaching problem solving in nonacademic or "everyday life" situations. Nine references are listed. (LMM)

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SOLVING PROBLEMS

February 1977

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The working paper reported here was written by James G. Greeno of the University of Pittsburgh, for the Skills Essential to Learning Television Project, of the Agency for Instructional Television.

SOLVING PROBLEMS

February 1977

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IR011 434

SOLVING PROBLEMS

In this essay I have been asked to present my views about the way children solve problems. The age group that is of special interest is in the range from ten to twelve--students in grades five and six.

I think it is useful to consider problem-solving processes in three general types of categories. These are (1) understanding, which includes noticing that there is a problem and representing the problem situation for oneself; (2) transformation, which includes processes of planning and performance of operations that are used in getting the problem solved; and (3) composition, which involves retrieving information from memory about ideas that are relevant to the problem and generating different ways that various parts of the problem can be fit together.

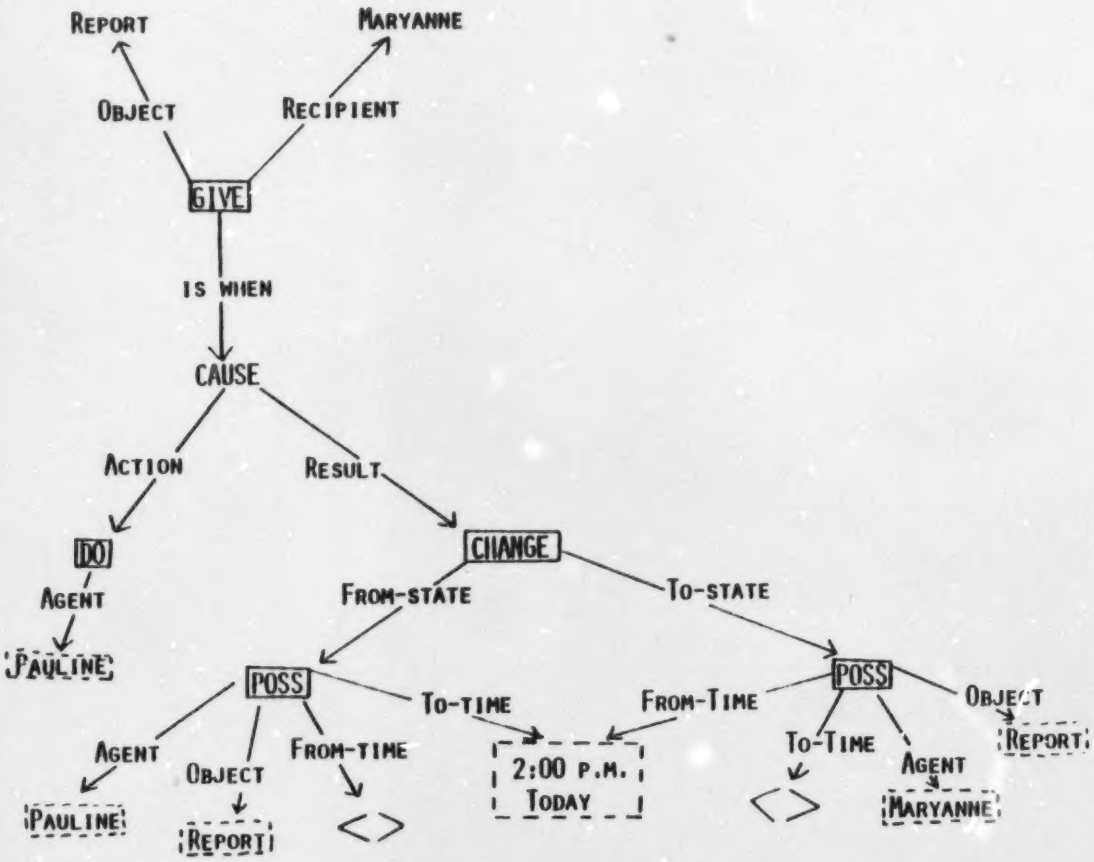
It is useful to make this distinction because different problems require different kinds of processes. To clarify the processes I have in mind, it is helpful to consider these relatively pure cases:

1. The process of understanding involves seeing the relationships among elements. This process has been explained most clearly in current theories of understanding language, in which the understanding process involves finding relationships among concepts. For example, when we understand a sentence such as "Pauline gave Maryanne the report today at 2 p.m.," we construct a repre-

sentation in which we identify "gave" as an action, "Pauline" as the agent who did the giving, "the report" as the object that was given, and "Maryanne" as the recipient of the giving. We understand further that there was a change in the status of the possession of the report; before 2 o'clock Pauline possessed the report, but after 2 o'clock it was possessed by Maryanne.

The process of understanding this sentence generates a representation that can be seen in a diagram, such as Figure 1. Various theoretical accounts of the understanding process have been worked out. The one used here is by Norman and Rumelhart (1975); the specific analyses of possession verbs was given by Gentner (1975). In the upper section of the diagram the basic relations of the sentence are represented: the action denoted GIVE is connected to the various other components by arrows indicating the kind of relationship in each case. Thus, Pauline is shown as the agent of the action, report is shown as the object, and so on. The lower section of Figure 1 shows additional relationships that are part of a person's understanding because the person knows the meaning of "give." Giving is an action, performed by the agent of the sentence (Pauline). The result of this action is a change, which means that a state called the from-state was in effect before the change, and a different state, the to-state, was in effect after the change. The from-state was a state of possession (labeled POSS) in which Pauline had the report. (Pauline was the agent of the possession, and the report was the object possessed). In the to-state, the report is the object that is possessed, but the agent who has it is Maryanne. Possession states also have time boundaries. The time that Pauline's possession of the report began is not specified, but the time it ended (called the to-time) is indicated as 2 o'clock today. That is the same time that Maryanne's possession of the report began, shown as the from-time of that state.[1]

FIGURE 1


REPORT
MARYANNE
OBJECT
RECIPIENT
GIVE
IS WHEN
CAUSE
ACTION
RESULT
DO
CHANGE
AGENT
FROM-STATE
TO-STATE
PAULINE
POSS
POSS
TO-TIME
FROM-TIME
OBJECT
AGENT
OBJECT
FROM-TIME
2:00 P.M.
TODAY
TO-TIME
AGENT
REPORT
PAULINE
REPORT
MARYANNE

The process of understanding a sentence is not usually considered an example of problem solving, although as I will argue later, it is involved in many situations that are. Nonetheless, there are standard cases of problem solving in which the main process is the apprehension of relations, and these are, therefore, primarily problems in understanding. The simplest examples are analogy problems of the kind that are used in intelligence testing. When a person is asked to select the best answer for "merchant : sell :: customer : (trade, buy, take, make)" the psychological process is predominantly one of identifying relations among the concepts. This process of identifying relations, viewed in a general way, is the process of understanding.

When a problem solver is working on a problem of understanding, the main requirements are to be able to identify the relations present among the elements of the problem, and to be able to generate an appropriate pattern that includes the elements and the relations that are apprehended.

2. Many problems can be described in the following form: There is an initial situation I, and the goal of the problem is to produce situation G that differs from I. There is a set of operators that can be used to transform the situation; the operators may have conditions that permit their application. A solution consists of a sequence of operations that transforms the situation from I to G.

A simple example of this kind of problem solving is a puzzle, sometimes called the Tower of Hanoi, where there are three pegs and a number of disks, graduated in size. In the beginning, all the disks are on one

of the pegs, and the goal is to move them all to another designated peg. Only one disk may be moved at a time, and at no time may a disk be placed on top of other smaller disks. Each move transforms the situation by changing the location of one of the disks. A solution is a sequence of such moves, leading eventually to the goal situation in which all the disks are stacked on the target peg.

Another kind of example of transformational problem solving is simple theorem proving, where the initial situation is a set of statements given as premises, the goal situation is a statement to be proved as a theorem, and the operations are rules of inferences that allow the derivation of new statements from the premises or from other derived statements.

The psychological process required to solve problems of transformation is called means-end analysis; this has been analyzed carefully by Newell and Simon (1972). Means-end analysis involves comparing the situation that has been produced with the goal situation, and trying to select operators that reduce or remove differences. The problem solver must understand the restrictions on application of the operators, and for most problems must proceed in an organized way, planning the search for solution by working on important general properties before dealing with less important details.

3. In a problem of composition, the main task is to arrange elements. In simple cases, the elements are given in the problem. An example is an anagram, where letters are given and the problem is to arrange them to form a word. In many arrangement problems the elements must be generated

by the problem solver; for example, in a crossword puzzle there are clues given, but the specific elements of the solution must be generated by the problem solver as part of the process of recalling words from memory.

The psychological process involved in solving problems of composition can be called constructive search. It involves a large data base stored in memory that can be used to generate partial trial solutions for the problem, and a complex pattern recognition system that is used to check the partial solutions. For example, in solving an anagram, a person often notices small combinations of letters that form pronounceable subunits of words. The recognition of potential subunits requires knowledge of the way that letters are combined in the language. The process of trying to form a word can sometimes lead to construction of a wordlike sequence that conforms to the rules of English spelling and pronunciation but that is not known to be a word by the problem solver. Thus, although most solutions of anagrams involve recognition of words, even in this simple situation the process of composition sometimes takes the form of constructing a novel pattern that fits a general set of constraints.

School Tasks as Problems To Solve

Much of the progress that has been made in the last decade in understanding problem-solving processes has resulted from paying close attention to the specific requirements of problem-solving tasks. This is a very different approach from that taken for many years, in which the effort was to identify general principles of behavior relevant to problem solving. I do not mean to suggest that there are no general principles of problem solving; however, earlier analyses were abstract in a way that interfered with the understanding of many important characteristics of problem solving.

To understand the problem solving of fifth- and sixth-grade students, and to begin to develop recommendations about instruction for improvement of problem solving, it is important to consider the kinds of situations in which these students are expected to solve problems, and the kinds of problems they are expected to solve. This does not imply that the curriculum already contains all the problem-solving experiences that it should. In fact, the school curriculum probably is quite restricted in the kind of problem-solving training that children receive, and perhaps some expansion in the kinds of problems used would be beneficial. But problem solving of the kind that is emphasized in the curriculum is extremely important, and many students are quite unsuccessful in the problem solving that is required for standard school tasks at the fifth- and sixth-grade levels. Therefore, it is important to begin with those tasks and consider them carefully. I will consider three school tasks as examples: problem solving in mathematics, understanding in reading stories, and understanding in science.

Mathematics: The most common kind of problem used in grade school mathematics is an exercise in computation. Consider a simple problem:

$$\begin{array}{r} 627 \\ \times 403 \end{array}$$

The student's task is to just "find the answer." Is this problem solving? If we consider the psychological processes involved in performing the task, we most assuredly should consider these exercises as a form of problem solving.

When a child has learned how to multiply numbers, the child has acquired a complex set of productions that are used to organize the activity of finding answers for multiplication problems. The procedure includes rules for selecting the information to use at each stage. (Begin with the two digits at the right, then keep the right digit from the bottom

row but move one digit to the left in the top row, and so on. When you have finished the top row, move one digit to the left in the bottom row and start again with the right-most digit in the top row, and so on.) The procedure also requires use of data that are stored in memory--mainly the basic facts of arithmetic (the multiplication table in this example). But much more is required, including knowledge of where to write partial results that are obtained, rules for carrying, special rules involving zeros, and others.[2]

Although the ability to do computation is generally not thought of as problem solving, it clearly involves the kinds of processes that are considered as problem-solving processes in current theory. Computations are primarily problems of the transformational type. First, there is an initial situation presented, and there is a goal (finding the answer). The goal must be achieved by a series of steps. At each step, there has to be analysis of the situation to see which of several operations can be applied. The process is organized according to a series of subgoals.

In the mathematics curriculum, situations that are labeled as "problem solving" often involve word problems, such as the following: "Barbara bought a 5-pound bag of sugar. She used 3-1/4 pounds to make jelly. How many pounds of sugar were left?" (Payne, May, Beatty, Wells, Spooner, & Dominy, 1972, p. 148).

The issue is just to determine what operation to perform on the numbers. This depends on understanding the relationships between quantities that are described in the problem. And the psychological process required to understand those relationships is quite complex.

Figure 2 shows the meaning structure that is given for the concept "buy" by Gentner (1975). When buying occurs two things happen: (1) There is a change in possession of the thing that is bought. In this problem, the seller is not named, so the previous possessor of the sugar is left blank, but after the event occured (at a time called t_1 in the diagram) the sugar was possessed by Barbara. (2) There is a change in the state of possession of money, with the buyer transferring money to the seller.

Figure 3 shows a meaning structure for "Barbara used 3-1/4 pounds of sugar to make jelly." The idea here is that Barbara caused a change in state of the sugar, from being in her possession to being gone. And she also caused a change in state from one in which there was 3-1/4 pounds of sugar (and presumably other ingredients, though these have not been mentioned) to a state where there was jelly.

I am concerned here just to show something of the complexity of the process of understanding simple sentences. We can think of structures like Figure 2 and Figure 3 as being constructed in the mind of the person who understands the first two sentences in the problem about Barbara and the sugar. That is a fairly complex achievement in itself, although it is the kind of thing that children are doing from the time they first begin to understand language.

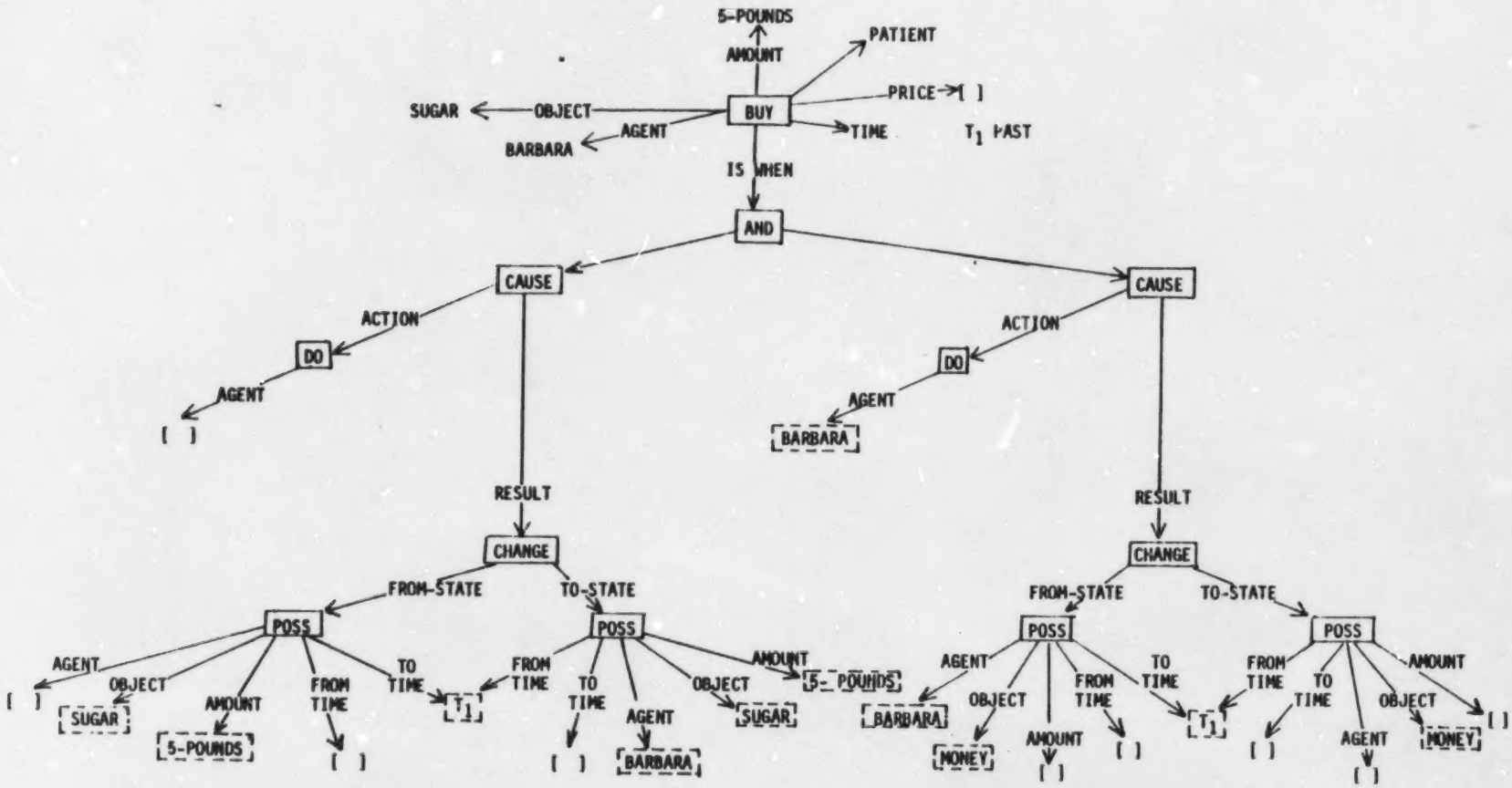
But the understanding of these sentences doesn't involve the problem as we consider it. That is stated in the final sentence, which asks, "How many pounds of sugar were left?" Suppose you have constructed representations of the kind shown in Figure 2 and Figure 3. You now have the question about how much sugar is left. How do you proceed?

Somehow you are required to connect the component in Figure 2 about Barbara's possessing five pounds of sugar with the component in Figure 3 about the change in state of 3-1/4 pounds of sugar. The problem solver must infer that some of the original sugar is left, and must use an arithmetic operation to compute the amount.

What makes word problems hard for students? That is a familiar and difficult question. We don't have anything like a complete answer, of course, but some features can be identified from what we know about language understanding. It is possible that there is difficulty in simply understanding sentences that include quantitative properties, though that has not been studied. (When somewhat younger children were studied regarding their understanding of simple comparatives, such as "more" and "bigger," it was found that difficulties of comprehension were present surprisingly in older children, so we might be surprised at the difficulty that fifth and sixth graders could have in simply representing sentences of the kind used in word problems.)

But if we assume that representations like Figure 2 and Figure 3 are constructed reliably, there are still at least two difficulties in solving a word problem that do not occur in an exercise such as "Find 5 minus 3-1/4." One is that in the word problem there is a great deal of information that is extraneous to the process of finding the answer. The fact that money was involved does not enter in this problem (though it could in another situation--many problems focus on how much someone spent in a trip to the store) nor does any of the information about how the sugar was used. So the student must select those features of the problem that are to be used and disregard irrelevant features.

FIGURE 2

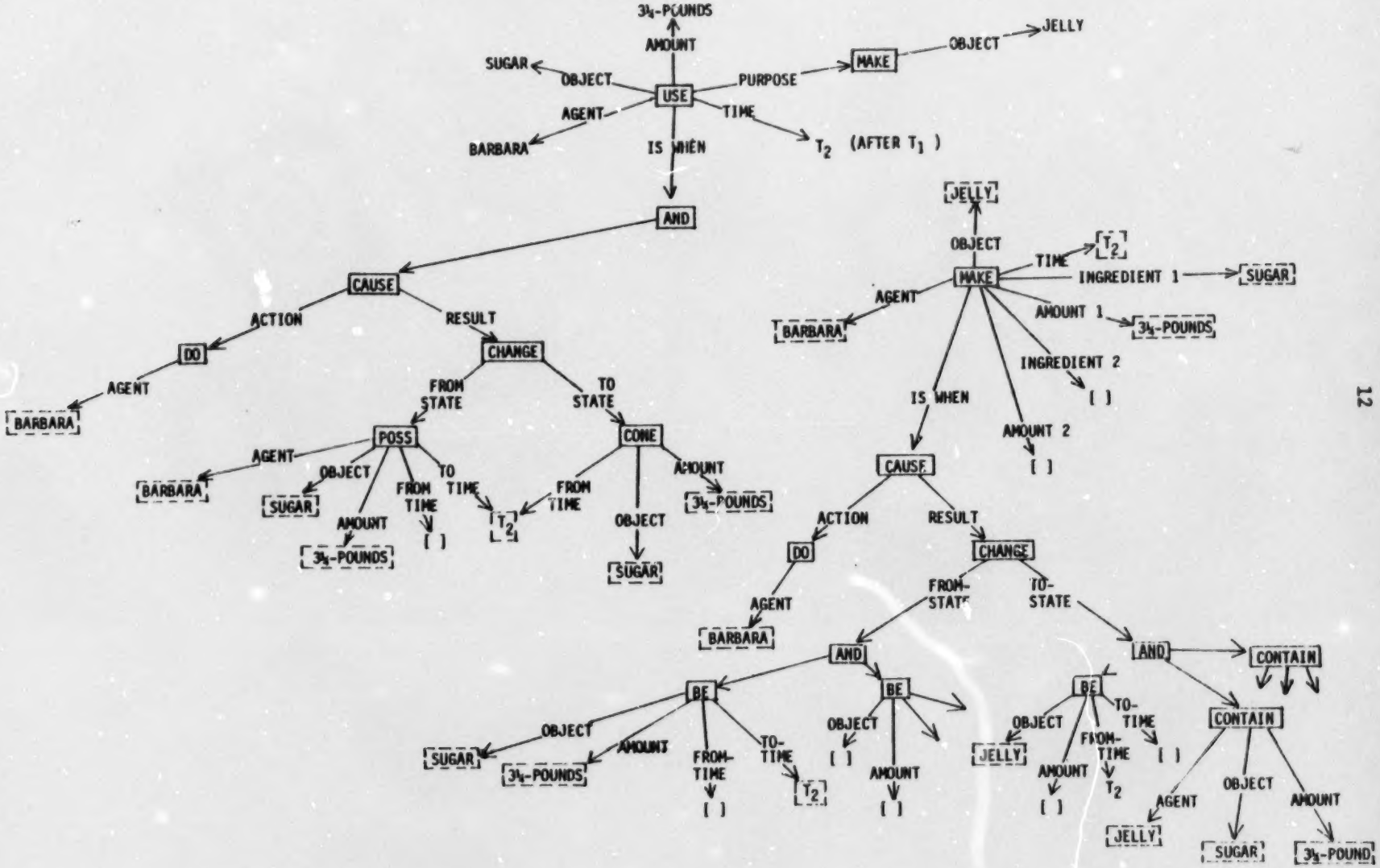


11

14

15

FIGURE 3


3¼-POUNDS
AMOUNT
SUGAR
OBJECT
USE
PURPOSE
MAKE
OBJECT
JELLY
AGENT
TIME
BARBARA
IS WHEN
T2 (AFTER T1)
AND
CAUSE
ACTION
RESULT
DO
CHANGE
AGENT
FROM STATE
TO STATE
BARBARA
POSS
CONE
AGENT
OBJECT
TO TIME
FROM TIME
AMOUNT
BARBARA
SUGAR
FROM TIME
T2
[ ]
OBJECT
AMOUNT
3¼-POUNDS
SUGAR
3¼-POUNDS
JELLY
OBJECT
T2
TIME
MAKE
INGREDIENT 1
SUGAR
AGENT
AMOUNT 1
BARBARA
3¼-POUNDS
INGREDIENT 2
[ ]
IS WHEN
AMOUNT 2
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CAUSE
ACTION
RESULT
DO
CHANGE
AGENT
FROM-STATE
TO-STATE
BARBARA
AND
AND
BE
BE
OBJECT
AMOUNT
FROM-TIME
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SUGAR
3¼-POUNDS
[ ]
T2
OBJECT
[ ]
AMOUNT
[ ]
BE
AND
CONTAIN
OBJECT
TO-TIME
FROM-TIME
CONTAIN
JELLY
AMOUNT
[ ]
T2
[ ]
AGENT
OBJECT
AMOUNT
JELLY
SUGAR
3½-POUND

Another difficulty is coordinating parts of the representations that must be put together to understand the question. In the problem about Barbara, the components that must be coordinated are Barbara's possession of five pounds of sugar (resulting from the action in Figure 2), and Barbara's possession of 3-1/4 pounds of sugar prior to the action shown in Figure 3. These two components must be incorporated into another schema, so that the question "How much was left?" has meaning and relates properly to the rest of the problem.

It seems clear that the solving of word problems in mathematics is primarily a process of understanding. Students are required to identify relevant relationships among components of a situation, select components of meaning structures that relate to the question, and coordinate these components with their mathematical knowledge. We don't yet have a thorough understanding of important aspects of this process, but the skills that are required seem clearly to be primarily in the domain of processes for understanding.

Reading: In the fifth and sixth grades, there is special emphasis on comprehension of the structure of stories. Students are asked to read stories, and then answer questions that depend on their having understood and remembered general information in the story. I have already remarked that the main feature of problem solving in mathematical word problems is a process of understanding. There seems little doubt that what students are asked to do in their reading instruction is also mainly a process of understanding.

The process of understanding a story has been studied by a few psychologists and linguists, but the work is very recent and tentative. The nature of the problem is clear: A story describes a number of things that happen; understanding the story involves apprehending the relationships among those events. A recent analysis by Mandler and Johnson (1977) presents one way of representing the main relationships in folk tales. The structure of the story includes a setting and a series of episodes. In each episode there is a main character, whose actions are related to a goal. The episode begins with a situation that elicits some reaction on the part of the protagonist (wanting something, or being angry about something, and so on). The episode continues as the protagonist performs actions that are oriented toward the goal. The episode ends when the protagonist achieves the goal, or when something else happens in the story. Another episode may begin with a different goal for the same protagonist, or with another protagonist.

Another process, that has not been analyzed yet in theories of story understanding involves making inferences about the characters in stories. In addition to apprehending the relations between events and actions through inferences about characters' reactions and motives, a reader also can make inferences about their personality traits, social roles, and general beliefs, based on their actions in the story.

The tasks that are found in reading texts for fifth- and sixth-grade students include reading stories and answering questions about stories. The process of reading mainly depends on understanding. Sentences must be understood (cf. Figure 1), and then the information in the sentences must be integrated into an overall representation of the story that includes relationships between the events and general information about the characters. Many of the questions students are

asked about stories involve retrieval of information. For example, if "Pauline gave Maryanne the report" was part of a sensible story, then that would be related to other events in the story in some way--probably by the motivation that Pauline had in performing that action. Someone who understood the story would know what that motivation was, and a comprehension question such as "Why did Pauline give Maryanne the report?" would simply call for retrieval of that information from memory.

Students are sometimes asked questions that begin to require processes of composition. (For example, following a story taken from a Norse myth about Thor and a giant, students are asked to name some personality traits that the Vikings apparently admired.) If students are asked to discuss situations that appear in stories, if they are asked to write stories of their own, or if they are asked what might have happened in the story if some specified event had been different, then they are clearly being asked to generate compositions. This requires arranging information they have in memory to meet the requirements of an essay or a story form.

Science: The science curriculum for fifth and sixth grades requires a considerable amount of reading and answering of factual questions based on reading. This requires skill in understanding and retrieving information from memory, as in the reading curriculum. However, the process of

understanding in science probably uses quite a different set of knowledge structures from those that are used in the understanding of stories in reading curriculum. The relations that are important in integrating the components of a story are primarily those of human reactions and motivations. The action of one character changes a situation, and some other character who is pleased or displeased with that situation then performs some response based on her or his reaction and general motivation, and that goes on to the conclusion of the story.

However, in science the personalities and motivations of people are not the important relations that integrate the material being presented. In most of the material presented to fifth- and sixth-grade students (and much that is in more advanced curricula) the major information involves analyzing complex systems or identifying general properties of some process (for example, the parts of the human circulatory system, or various properties of light energy). The propositions in the text are integrated by relationships such as A being part of B, B having a certain function in A, and A having a property C, rather than A being the agent of action B, which has object C, and so on. The relations between sections of the text involve phenomena that illustrate general principles and facts that provide evidence for general propositions, rather than events that cause personal reactions of story characters.

It is a reasonable conjecture that the process of understanding text material in science and other subjects (such as social studies)

requires a set of knowledge structures that are different from those that support understanding of stories. (A simple way of stating this possibility is that a student may know how to read general materials well, but not know how to read science and other subjects.) Relevant training would involve instructions in identifying general principles, in identifying the relationship between principles and examples, and in identifying the relationship between principles and evidence that supports or is counter to the principles.[3]

In addition to reading text materials and understanding the information presented, students are asked to carry out experimental procedures and explain phenomena. An example from a fifth-grade science text (Craig & Hill, 1965) includes a procedure for measuring pulse rate. Measurements are to be taken when the person is rested and also after vigorous exercise. This is followed by the question, "What is your explanation for the difference in rate of heart beat?"

Two kinds of problem solving are involved in this kind of exercise. First, the student is required to solve a problem in which the goal is to obtain a specified kind of measurement. The procedure for obtaining the measurement is described in some detail, but successful application still requires some nontrivial analysis of the situation and evaluation of results. This fits in the class of transformational problems, where operations are applied in situations to produce specified results.

The other kind of problem solving involved here is composing an explanation of a phenomenon. That requires knowledge on the part of the student about what an explanation is like. In addition, specific information about the causes of heart rate must be retrieved from memory and fit together to form an explanation. In this instance, the necessary information apparently must come from two paragraphs that are presented just before the exercise in measuring pulse.

> When the cells need more oxygen so that energy can be released, your heart beats faster. This also allows carbon dioxide to be taken back to the lungs much faster than it would be otherwise.
>
> When do you think your cells need oxygen more quickly? When would they need to get rid of carbon dioxide more quickly? (Craig & Hill, 1965, p. 251)

The general category of problem solving involved when a student is required to <u>construct an explanation</u> is <u>composition</u>. Information relevant to the problem must be retrieved from memory and arranged in a way that fits general prescriptions. In science exercises, the problems of composition are not defined very well for the students because the criteria for having an explanation are not specific, and the information to be used in the explanation is often not presented in sufficient detail to make its relevance clear to the student.

Facilitation of Problem Solving

A few general principles need to be kept in mind in thinking about attempts to increase children's problem-solving skills.

First, it is not a good idea to think of problem-solving skill as a single, uniform capability. Problems of different kinds require substantially different skills. I believe that the processes of understanding, planning and transformation, and composition are useful in pointing out broad categories of processes that are important in fairly general categories of problems. There may be some very general abilities that cut across the broad domains of problem solving, but we can only guess at what they might be. I am skeptical about attempts to provide training even in such skills as understanding, planning for transformational problems, and composition, although I wouldn't consider such attempts completely hopeless. I do think that efforts to train something called general problem solving is practically hopeless at this stage of our understanding.

To be successful, training must have an identified objective--something that the students should be able to do at the end of training that can be identified by them as well as by some objective assessment. This means that instructional experiences intended to facilitate problem solving should have objectives that identify relatively specific kinds of problems that students are supposed to get better at solving. An analogy may be useful: It is possible to train someone to be better at tennis if you teach the person tennis, or it is possible to improve someone's skill at basketball or a large number of other games.

It is not clear what one can do to help someone become a better athlete, apart from teaching the person some specific athletic skills. I believe the same holds for problem solving. There are various kinds of problems that we can teach people to solve more successfully. But I don't believe that problem solving in general is something that we know how to instruct.[4]

A second principle is that problem solving does not occur in a vacuum. Problem solvers reach solutions using their knowledge of the problem situation or of some similar situation from which they can transfer knowledge. Thus, even when problem solving uses very general skills, it also depends on some quite specific knowledge either about the problem situation or a related one. Thus, it is important to identify information that would be useful to students across a variety of problem-solving situations, and to teach them that information, as well as give them experience in using the information in solving problems.

Four general aims might be adopted for an instructional program focused on problem solving. These involve rather different objectives and concepts, although in a series of programs, different objectives could be adopted for different programs. The four possibilities that I see are (1) strengthening students' skills regarding the kinds of problems they are expected to solve in the ordinary curriculum;

(2) enlarging the domain of problems that students are able to work on by providing them with additional knowledge to have available; (3) expanding the range of students' skills by training them in different kinds of problems from those they ordinarily encounter in school, though still related closely to the school environment; and (4) identifying and analyzing problems that are clearly nonacademic, such as personal and social problems, and teaching approaches to these problems.

1. Strengthening Skills for Conventional Problems. Students must do well in problem solving in order to do well in the tasks that are included in their ordinary classroom work. In the fifth and sixth grades, there is special emphasis on problems that depend mainly on the process of understanding. Understanding would probably be the most important skill to try to facilitate at this level. Unfortunately, very little is known about how to teach children the skills required in understanding, so one must be speculative. On the other hand, there are some general principles that almost certainly are applicable.

First, it should be helpful to make students aware that understanding is something that they do, it's not something that just happens to them. When a student is trying to understand something there is a goal that the student can try to accomplish. Students do not need to feel helpless when there is something they don't understand.

Second, an important part of understanding involves attention to the information in a situation that makes the different parts fit together, rather that to the features that distinguish the different parts of the situation. There are probably different ways of identifying the

important global features of situations, depending on the kind of situation. In understanding stories, it appears to be most important to ask Why? and What happened because? Most stories are held together by the characters' motives and reactions. A student asking, "Why did so-and-so do that?" is thinking about the characters' motives. And a student asking, "What happened because so-and-so did that?" is thinking about the outcomes that result from the actions in the story. The comprehension of a story is primarily a process of seeing what it is that connects the various actions into a coherent sequence, and this process should be facilitated if students are trained to attend to the motivational and causal relationships that provide most of the connections in most stories.

Understanding in content areas such as science probably involves attention to a somewhat different kind of relational structure than does understanding of stories. Most of the topics in elementary-school science seem to involve either a whole-part organization, or an object-property or process-property organization. The topics that are organized with the whole-part principle discuss component systems that go together to form a larger system. (An example is the circulatory system, divided into its components.) The topics that are organized with the object- or process-property principle discuss different features or characteristics of some object or process. (An example is the nature of light energy where various characteristics of light are presented.) The process of understanding should be facilitated if the student learns to organize the information in these major ways—

identifying what the parts are of a general system and what the system is, or identifying the characteristics as properties of something.

Problem solving in mathematics probably is the task in the curriculum most often identified with problem-solving skill. A reasonable conjecture is that in solving word problems a student should understand the text before trying to decide what computations to do. This intermediate thinking process can sometimes be facilitated by use of a diagram, although the main issue is to apprehend the relations among the quantities in the problem. In any case, training in which students became more aware of the need to understand the problem--rather than just get the answer--would be likely to strengthen their skills in problem solving in the mathematics curriculum.

Computational exercises, the main component of the mathematics curriculum, are often not thought of as involving skill in problem solving. They do, however, but because they usually are not classified as "problems," we generally fail to give children credit for a great deal of problem-solving skill that they actually possess. It probably would be useful for students to learn to think of mathematical calculations as a form of problem solving. Rather than focusing on situations where students do not understand what to do, implying that problem solving is hard, why not explain to them what problem solving involves, and point out that they do a great deal of it all the time? With an improved understanding of what problem solving is and confidence that they are good at it (at least in situations where they have learned the relevant skills), students should be able to develop spontaneous

approaches to a variety of problem situations. The main features of a computational problem are the goal and the organization of work into subgoals. The goal can be stated in a way that relates the problem to general quantitative concepts. This would provide one kind of understanding of what the problem is about and would also call attention to an important feature of the problem-solving process. Students could also learn to think of difficulties that come up as subproblems that must be solved in order to go on with the main procedure. (An example is having too large a digit to subtract, requiring the operation of borrowing.)

2. Enlarging the Knowledge Base for Problem Solving. An important way in which students can become stronger problem solvers is by acquiring additional knowledge and technical skill to apply in problem-solving situations. There are undoubtedly many different domains in which knowledge relevant to problem solving could be presented. Two that come to mind are knowledge about how to obtain certain kinds of information needed for a problem, and knowledge about how to obtain quantitative measurements needed for a problem.

The problem of obtaining information involves a variety of information sources. Some problems involve special books, such as dictionaries and atlases, which students could be shown and taught to use. Other skills are more technical, such as knowledge of how to read graphs, tables, and charts. Skills of this kind can be presented as tangible procedures, so that a definite instructional objective is clearly present. But they also should be shown in the context of their use in problem solving, rather than simply as techniques to be mastered.

Knowledge of how to obtain measurements also is an important component of many problems. There are technical aspects of measuring that often are not known by students, such as correct placement of a ruler, and making sure that a measuring cup is level. But there also is an interesting and important set of skills involved in choosing an appropriate instrument for obtaining measurements. For example, a class might want to have fruit punch at a party. How can they decide how much to buy? If they decide that everyone should have two glasses, they must decide how much punch it takes to fill a glass, they must determine a way of measuring the liquid in a glass, and so on.

3. Expanding Students' Problem-Solving Skills. The problems that distinguish most of the school work of fifth and sixth graders mainly depend on skill in understanding. Since other kinds of skills are important in many problem-solving situations, it would be reasonable to try to supplement the experience that students have in the regular curriculum with problems that give exercise in other skills, to provide a more balanced set of experiences.

Most of the previous efforts to introduce special problem-solving instruction into classrooms have emphasized training in creativity, imaginative thought, and flexibility. It is widely believed, with considerable justification, that school activities are heavily unbalanced in the direction of situations where there is a correct answer, and students are almost always engaged in trying to give an answer that has been defined as correct by the teacher and text. In response to this, it is reasonable to supplement the curriculum with training in situations where no single correct answer is available, but where students are encouraged to generate a variety of interesting responses. A concise review of this

literature has been given by Davis (1973).

A major effort in problem-solving instruction is to encourage a positive attitude toward having ideas, even, or especially, those that seem unusual and fanciful. The kinds of problems most often used involve a need for some invention, and students are encouraged to produce a wide variety of suggestions that relate to the problem. It is important in encouraging imaginative thought to get students to postpone critical judgment about their initial ideas. Evaluation of suggestions is important, but if a person only puts forward those ideas that are sure to work, creative production of ideas will be severely inhibited.

The process of generating a large set of alternative ideas fluently is an important part of the process of composition, and problems of composition have at most a light emphasis in the fifth- and sixth-grade curriculum. Instruction related to the process of writing, or composing songs, or making paintings could be a valuable supplement to the usual curriculum. These exercises have the virtue of involving a definite task, which seems lacking in exercises where the student is just supposed to "think of things." However, they also avoid the constraint in which only one answer is correct. Programs that deal with creative composition should emphasize the processes of producing different ideas and alternative definitions of the problem to be solved. Simple technical issues about the structure of a composition are important, but often are emphasized to the exclusion of the more free-floating and imaginative aspects of creative work.

4. Problem Solving in "Everyday Life". There is a strong temptation to try to design instruction that students (and other people) will

find relevant to their everyday experiences. That is laudable as far as it goes. However, the goal of relevance is sometimes used to justify activities that do not make any kind of sense other than some vague apparent connection to things that might happen to some of the students in some situations. It should always be possible to say in a quite definite way what it is that students are expected to learn from the instruction they are receiving.

I am not very sanguine about the probable effectiveness of trying to make better general social problem solvers out of school children. The problem is that the strategies that seem to be applicable are so general that it is hard to say what skills the children will acquire.

On the other hand, it is quite possible that a productive program could be developed using the idea that children are very successful at solving a host of problems already, and it would be interesting and useful to them to understand how their own problem-solving skills work. To get from one place to another requires considerable planning and decision-making skill (deciding on a route, selecting a means of transportation, etc.). Going to the store requires planning--being sure there is enough money and that the goods can be carried home. Setting the table for a meal involves a large set of subgoals in which various kinds of objects need to be found and placed properly. One could go on indefinitely. An awareness of the various components of successful problem solving that the child already executes with little or no difficulty would provide an increased understanding of the process of problem solving. And then showing the application of those same principles in situations where the children probably would not already have learned solutions could encourage the students toward confidence in their own skills in problem solving.

Footnotes

[1]Of course, constructing the relations within the sentence is only part of the process of understanding. In addition, the understander connects the information in the sentence with other background knowledge as well. Theoretical work that clarifies some aspects of this process in understanding of stories has been done by Minsky (1975).

[2]The process described here involves a mechanical algorithm for computing the answer for the problem. When a student performs the computation, it is hoped that there will be understanding in addition to correct calculation, and this is not included in the characterization given here. Understanding of computation is an important topic, although a somewhat technical one. I have presented some tentative thoughts about that topic elsewhere (Greeno, 1977).

[3]The distinction I make here between understanding of stories and understanding of science in the elementary grades is not meant as a general distinction between literary and scientific thinking. In more advanced work, students learn to analyze works of literature into their components and to consider their abstract properties, such as theme, setting, plot, characters, etc., in relation to general frameworks used in criticism. It is quite possible that the patterns of thinking that occur in more advanced forms of literary analysis and scientific analysis are similar in significant ways, although I do not know of any analyses that have tried to compare these except in very general ways.

[4]It is interesting to pursue the analogy a bit further. An important part of athletic training involves conditioning exercises, which although

they vary somewhat from sport to sport, clearly produce a condition that affects ability in activities other than the one for which the individual is specifically preparing. It is possible that there are aspects of problem solving that are analogous to general physical strength or endurance, and most individuals can provide plausible suggestions about what they might be. However, I know of no evidence that provides convincing support for any of these attractive conjectures.

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